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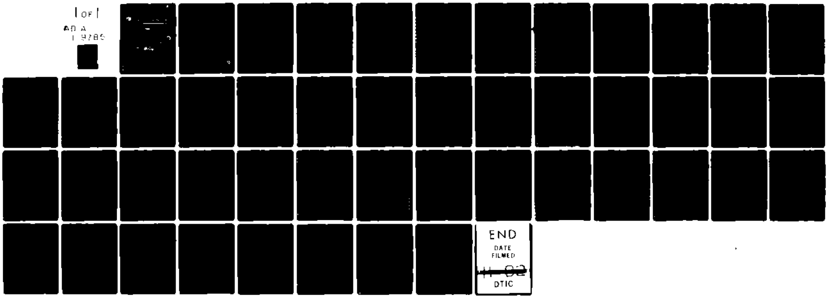
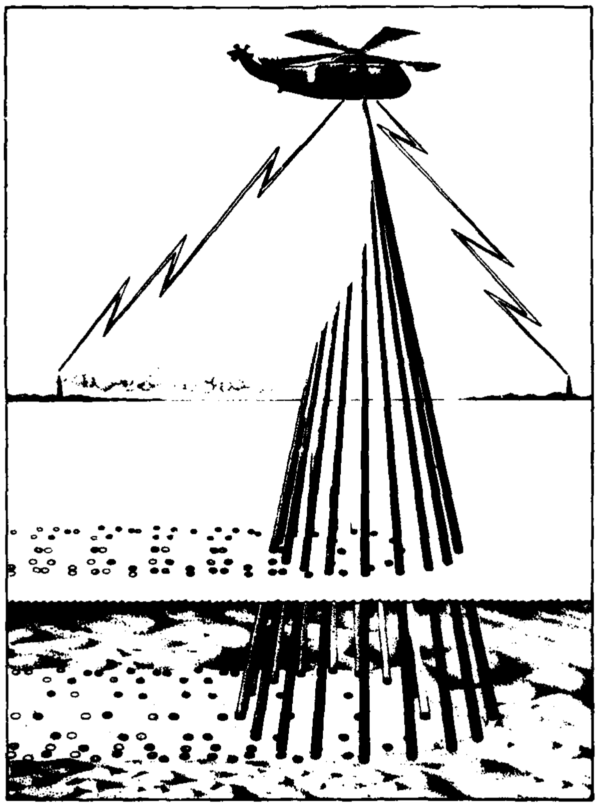


NORDA Technical Note 161

Naval Ocean Research and Development Activity
NSTL Station, Mississippi 39529

HALS Post Processing Software Design



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H.J. Byrnes

Mapping, Charting, and Geodesy Division
Ocean Science and Technology Laboratory

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ABSTRACT

This report discusses software that was designed and developed to process Hydrographic Airborne Laser Sounder (HALS) data tapes. The HALS survey produces tapes containing navigational, heading, altitude, and various housekeeping information, as well as raw laser ranging data from which ocean depths are to be extracted in a post-mission processing mode.

The software performs its tasks in four sequential processing passes. During Pass 1 (WAVEFORM processor) optical properties of water in the Survey area are quantized and evaluated; during Pass 2 (NAVAID processor) navigational information is edited and the aircraft's position is computed; Pass 3 (ATTALT processor) corrects for ocean waves, evaluates system performance, and locates the laser spot on the ocean bottom; Pass 4 (GRID processor) reconciles ambiguity among dense, noisy depth and position information and produces a minimum variance sparse grid of depth estimates.

Pass 1 processing techniques are based on research results concerning depth measurement bias caused by light propagation in sea water. The bias estimates result from a Monte Carlo simulation performed by Guenther and Thomas (1981).

Pass 2 utilizes computer/operator interactive CRT display techniques for editing purposes and computes position via an interactive process using Sodano inverse formulas. The code used for computing positions was acquired from the NAVOCEANO Computer Branch (1972).

Pass 3 utilizes optimal filter techniques to resolve aircraft altitude, pitch, roll, and sea surface waves via a minimum variance solution on the slant range laser measurement from aircraft to sea surface. The dynamics of the laser scanning pattern and sample sequence permit the state vectors of the optimal filter model to operate with distinct separation in correlation times (Byrnes and Fagin, 1978).

Pass 4 also operates via optimal filter theory and is designed to treat both depth error and position error simultaneously. The minimum variance gridding process takes advantage of redundant observations and generates a product with reduced random error (Byrnes, 1979).

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CONTENTS

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ILLUSTRATIONS

FLOW CHARTS

HALS POST-PROCESSING SOFTWARE DESIGN

1. INTRODUCTION

The purpose of this document is to specify the software architecture for post-survey processing of the Hydrographic Airborne Laser Sounder (HALS) survey data. The post-processing software performs data read, data scale, data correction, data edit, data display, data smoothing, data thinning, data selection, tape write, print, and plot functions. The products generated via this software are intended to be evaluated by a hydrographer for selection and merging of laser depth data onto hydrographic smooth sheets.

A post-processing scenario covering the overall treatment of HALS data is presented in section 2. A functional summary indicating how the scenario is to be effected is presented in section 3. Organization of the processor module specification is discussed in section 4. Sections 5, 6, 7, and 8 describe the detailed functions and the supporting subroutines for the WAVEFORM processor, the NAVAID processor, the ATTALT processor, and the GRID processor, respectively.

2. POST-PROCESSING SCENARIO

During a typical HALS survey mission, laser slant range information, positioning information, heading and attitude information, and general housekeeping information will be recorded on tape cartridges. Upon completion of a survey, the data tapes will be removed from the helicopter for post-flight data reduction on the Naval Oceanographic Office (NAVOCEANO) shipboard computer. The initial step of the data reduction process is to read and deblock the data tape and merge the laser slant range information with external environmental inputs.

At this point the HALS observations contain errors from multiple sources. These sources include: (1) errors in the determination of the aircraft's true position, altitude, and attitude; (2) inaccuracies in determining the true shape of the sea surface; and (3) contamination of the laser slant range measurements by various environmentally caused biases and random errors. To deal with these multiple error sources, optimal filter techniques are applied to some aspects of the post-processing. However, before the optimal filters can be applied, the environmentally caused biases must be reduced and gross navigation errors need to be removed.

Provisions have been made in the HALS hardware to digitize complete laser return waveforms at low pulse repetition rates (2 Hz). These waveforms will be examined to determine system amplitude response and environmental correction parameters. The amplitude response and environmental correctors will be used in conjunction with the observed incidence angle to form bias correction estimates, which will be applied to the laser slant ranges. Since these are fixed or slowly varying temporal or spatial biases, the sparsely sampled bias correctors can be applied to all the rapidly sampled (400 Hz) laser observations in the immediate space/time domain.

Navigational information is stored on the HALS tape in the form of range measurements, or time difference, rather than computed positions; this allows us to edit and correct the individual elements of information prior to position computation. A series of range measurements, or time differences, will be displayed on a CRT and evaluated by the operator for a spike or a lane jump. When all spikes are detected and removed from the navigational information, gross errors will be removed from the computed position. To ensure that all gross errors are removed, the computed positions are displayed and further evaluated by the operator.

After editing position and removing the bias from the laser slant ranges, the laser measurement from the aircraft to the surface of the water is processed in a minimum variance solution. The purpose of this process is primarily to determine wave corrections and altitude above the mean sea surface, and to statistically reject observations that contain excessive error. This is the first application of rejection criteria in the processing. When an observation fails the "aircraft to sea surface" criteria, the accompanying depth measurement is also rejected because an acceptable wave correction cannot be calculated for that particular observation.

The applied minimum variance solution is in the form of an optimal filter, with state vectors representing aircraft altitude, roll, pitch, and sea surface. Projection equations are executed for a given situation of roll, pitch, and altitude to provide an estimated slant range from aircraft to sea surface. The estimated slant range is subtracted from the observed slant range, and the result becomes an observation. The observation is then processed through error propagation equations updating the roll, pitch, and altitude at each laser return. The system can be modeled to provide roll and pitch directly from the laser measurements or can be modeled to track error in roll and pitch of an inertial unit. The major advantage of using an inertial attitude measurement unit is that the attitude information derived from it is more reliable when a portion of the HALS survey pattern falls over land.

Basic assumptions included in the model are that aircraft motion varies slowly while the state vector representing waves varies rapidly because of the sample pattern generated via the scanning HALS mirror. This separation in correlation time is an important factor in the separation of the waves from the other vectors of the system. The minimum variance solution on the "aircraft to sea surface" slant ranges will also provide an excellent detection system for any systematic errors generated by misalignments occurring in the manufacture of the scanner. Misalignment errors will show up as oscillations correlated with scan rate.

Upon completion of the "aircraft to sea surface" slant range processing, a wave correction is applied to each slant depth, and a position on the sea surface relative to the aircraft is supplied. The slant depth, still contaminated with random error as well as residual bias, is used to compute a somewhat noisy position on the sea floor. A two-dimensional optimal filter, which deals with both depth error and horizontal position error simultaneously, is then applied. This optimal filter takes the form of a grid where all the laser depth observations within the four immediately adjacent cells are used to calculate depth estimates at grid intersections. The optimal gridding is similar conceptually to polynomial surface fitting, except that we can select any grid interval and can impose any bottom slope restrictions without changing the computer processing load and can deal with both position error and depth measurement error simultaneously. (The spacing of the grid and the imposed bottom slope control defines the frequency response of the processing.) For any given swath of data, the post-processing frequency response can be increased merely by assigning smaller values to the grid interval. The penalty for this, though, is a reduction in accuracy since accuracy is a function of the total number of observations incorporated into any given grid estimate.

As with any processing based on optimal filter theory, a covariance matrix is the integral element which governs the weighting and incorporation of individual observations into the data set. Each grid estimate is represented by a diagonal term of the covariance matrix all the way through the grid processing. The covariance matrix comes into play in establishing rejection criteria when incorporating data into

a grid. As more data is incorporated into the grid, the standards for incorporating the next observation become more stringent, and a new observation must be more closely in agreement with the bottom that has been established, or it will be rejected. The evaluation takes into account simultaneously bottom slope, position error, and depth measurement error. At the end of the process, the covariance matrix reflects the number and proximity of observations incorporated into the individual grid estimates and can be used as data quality indicators. A grid of quality designators is printed with the grid of depth estimates on output and can be used to evaluate the overall survey quality and the degree to which agreement can be expected between depths derived from sound boats and depths determined by HALS.

Depth measurements that have been rejected will be analyzed to determine if any pattern of rejection exists. If many rejections occur in some particular location, the area may require resurveying with a higher resolution. A pattern of rejections infers that bottom slope is greater than modeled and that a survey system capable of higher frequency response is required. Trade-off between aircraft speed, laser swath width, sample density, and grid size all affect frequency response and are discussed in detail in Byrnes (1979).

3. FUNCTIONAL SUMMARY

The functional block diagram of the post-processing is shown in Figure 1. Four processing passes are indicated.

Pass 1 uses the recorded Tektronix 7912 digitized laser return waveforms to generate environmental bias factors, which will later be applied to laser slant depth. The bias factors are sent to disk along with statistical information on environment. Display of the digitized waveform is via a graphic display unit under keyboard control. As data is read from original data tape on Pass 1, navigation data for Pass 2 is loaded directly on disk to reduce tape handling.

Pass 2 deals with the recorded navigation data where a plot of the ranging information is prepared and displayed. The operator may interact to edit or modify the ranging information via the keyboard. Upon completion of the edit task, positions are computed, displayed and evaluated, and then stored on disk.

Pass 3 uses slant range laser measurements from aircraft to sea surface to estimate altitude, attitude, and wave height and displays results of system operation for evaluation. The slant depth is corrected for environmental bias and wave error, then combined with position information and direction cosines to compute depth and assign locations for each laser sounding. The results of Pass 3 (time, position, and depth) are stored on disk, then copied to magnetic tape via word blocks generated by a 6000 word buffer. The first automated edit function is performed during Pass 3 where observed laser ranges from aircraft to sea surface are compared to estimated ranges on a statistical basis. When an aircraft to sea surface range fails the statistical test, the accompanying laser slant depth observation is eliminated from the data group; thus, some "wild" depths will have been removed. The data group passed on, because of system design, contains more observations per surveyed area than could possibly be plotted on any normal scale chart, and the distribution is such that data overlap and depth disagreement occur at the overlap. The quality of the depth observations after Pass 3 is affected by: (1) residual bias errors caused by our inability to correct precisely for the environment, (2) random errors caused by onboard signal processing and quantizing hardware, (3) random errors caused by our inability to remove all waves, and (4) random "wild" errors caused by reflections from "things" other than ocean bottom.

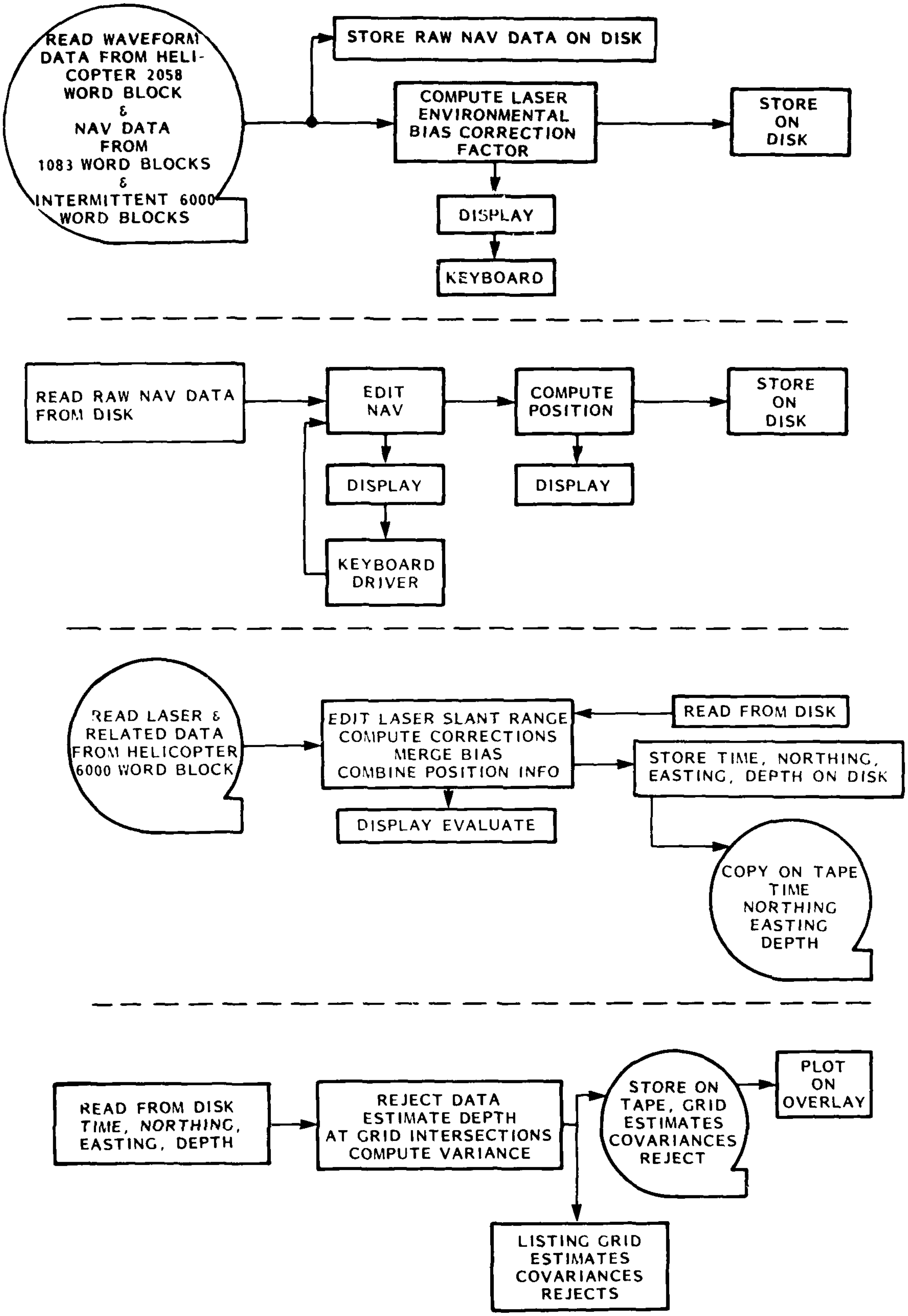


FIGURE 1. POST PROCESSING VIA PDP 11/60

The function of Pass 4 is to further edit the "noisy" data passed during Pass 3 and to improve data accuracy by taking advantage of redundancy inherent in the distribution of HALS observations. The program accepts dense noisy depth and position information from which it produces a minimum variance sparse grid of depth estimates wherein data ambiguities have been reconciled. Data is accepted or rejected on a statistical basis keyed to a covariance matrix. Output from Pass 4 consists of a grid of depth estimates, a covariance matrix, and a rejection pattern. These products are output on magnetic tape and on a line printer. The tape information can be plotted as an overlay to a smooth sheet if desired; in any case, these outputs provide the hydrographer with the material to evaluate and select data for hydrographic smooth sheets.

4. PROCESSOR SPECIFICATIONS

In the succeeding sections the four HALS post-processing passes are described as processors. The WAVEFORM processor (Pass 1), NAVAID processor (Pass 2), ATTALT processor (Pass 3) and GRID processor (Pass 4) constitute the four main processing modules; the total HALS post-processing package contains these four main processors and a combined total of fifty-two subroutines. Each processor is designed as a separate computer program but must be exercised in sequence correlating with its respective pass number. Any particular pass may be repeated any number of times, but no latter pass should be attempted without first having exercised all the lower passes at least once.

The processor module specifications presented here primarily address software objectives, i.e., describe what the programs should do. External specifications describing the exact representation of the program to the user and specifications describing how the program is constructed (structure, interface, and code) will be reported in an appendix.

Each processor specification consists of (1) a general description of the module function, (2) a description of the relevant algorithms and comments, (3) a flow chart providing an overview ("walkthrough") for each processor module and supporting subroutines, and (4) a description of the subroutines required by each processor module. Each subroutine is further described by function, relevant algorithms, and comments.

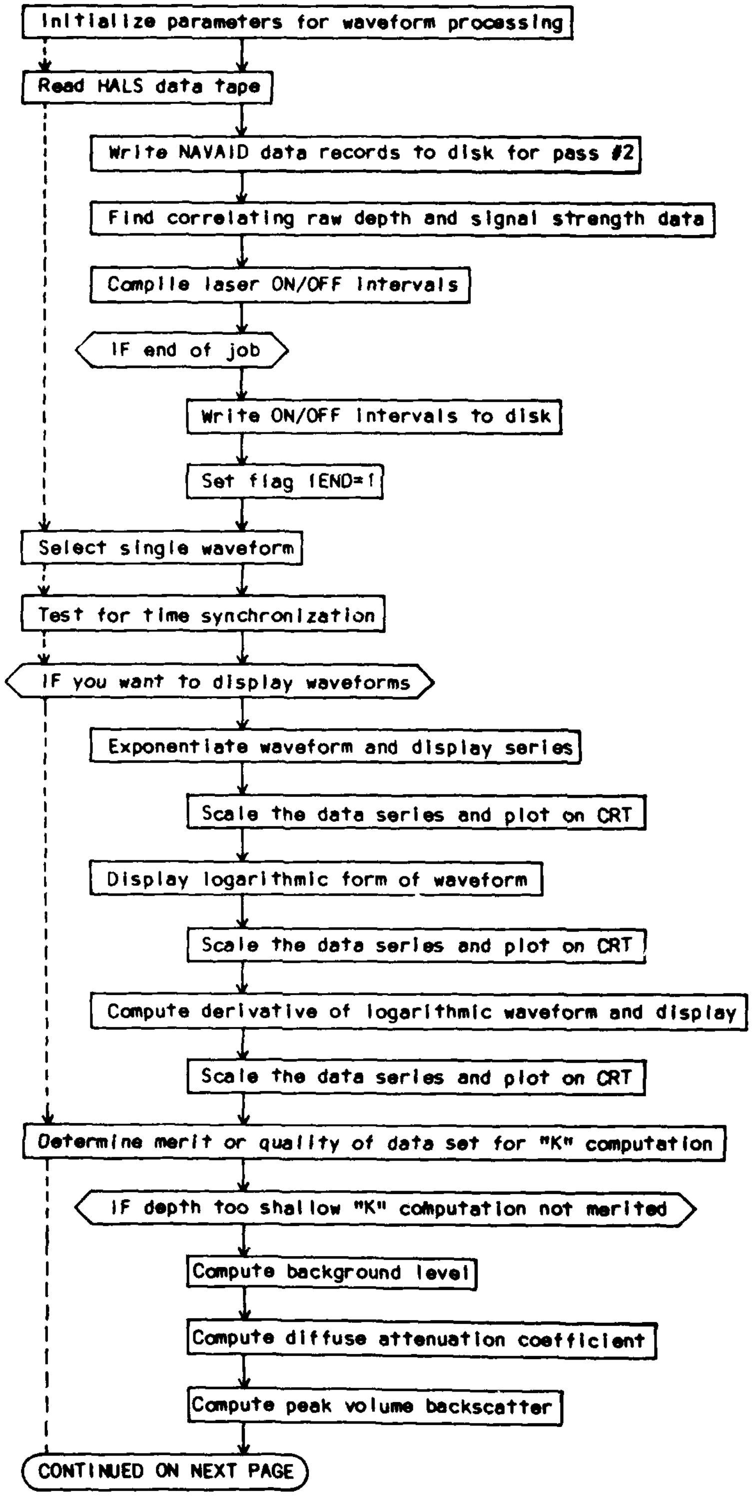
5. WAVEFORM PROCESSOR

Function:

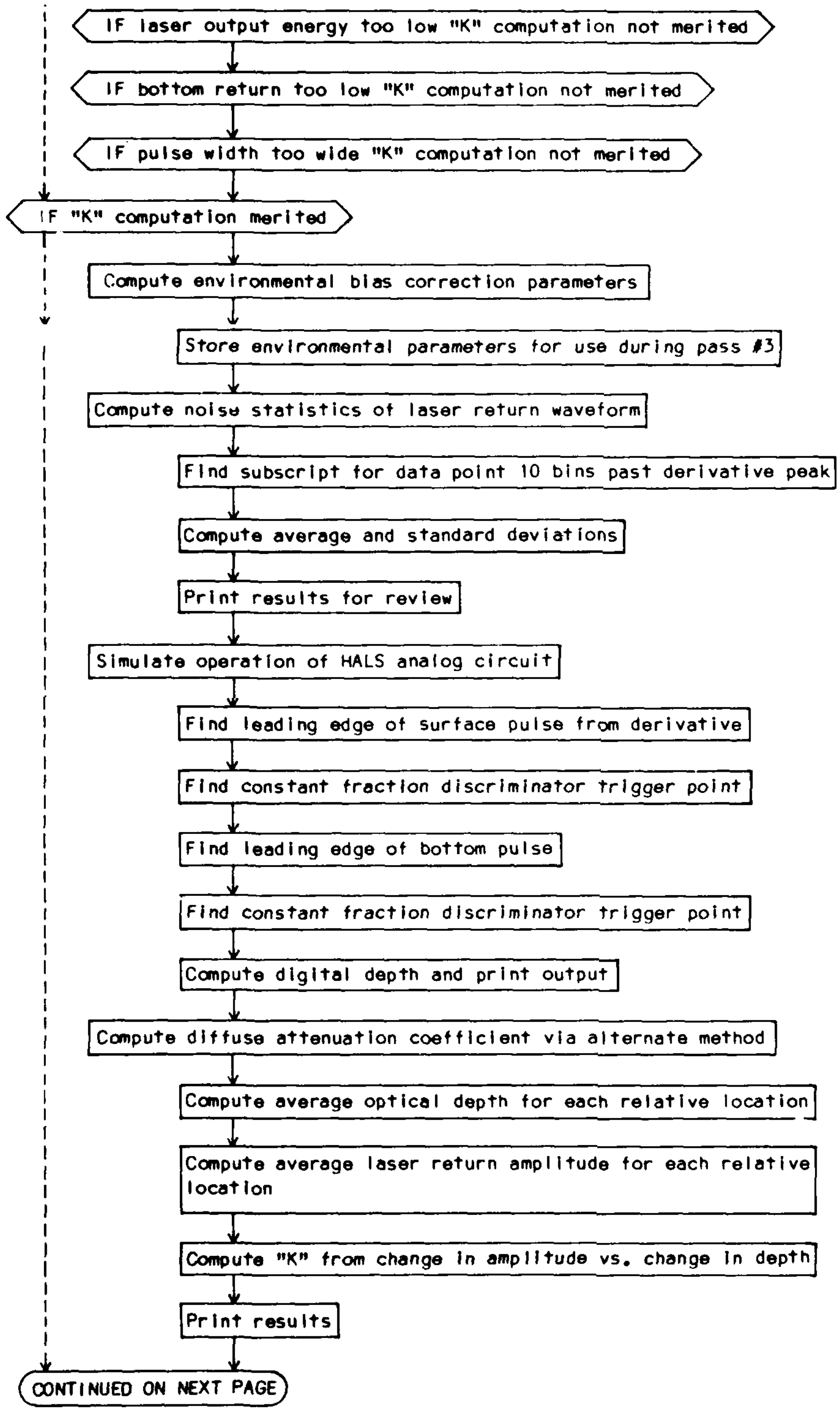
This first data pass provides the hydrographer with an initial look at the HALS general system response to the overall environment encountered in a specific survey area. The program operates on the digitized waveform to generate bias parameters for display and for later use during Pass 3 to compute bias corrections for each laser slant depth observation. The bias parameters include (1) a "K" value derived from the slope of the log of the laser volume backscatter, (2) an average background level determined from that portion of the digitized waveform which occurs after the influence of the bottom pulse, (3) a value "B/K" representing peak volume backscatter, and (4) the computed slope of the volume backscatter.

In addition to providing bias parameters, the digitized waveform is processed via a simulated HALS analog detection system to compute "depth" from the waveform for comparison with depth as determined by the HALS analog circuit, the comparison is displayed to the operator. A secondary "K," computed from change in optical depth

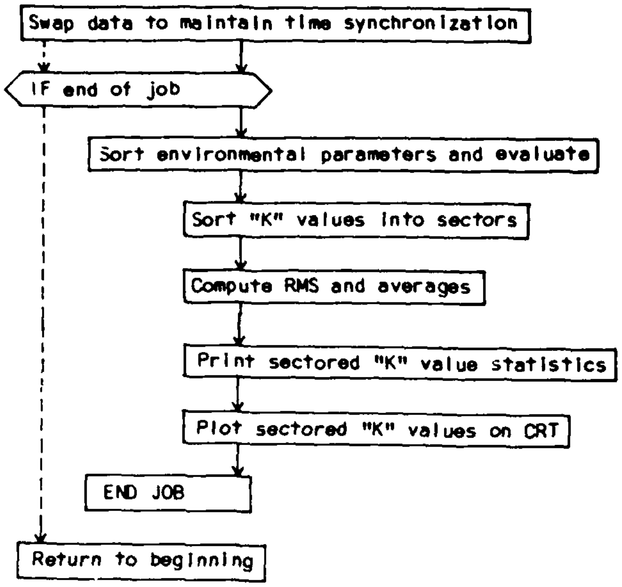
WAVEFORM PROCESSOR FLOW CHART



WAVEFORM PROCESSOR FLOW CHART (continued)



WAVEFORM PROCESSOR FLOW CHART (continued)



vs. change in amplitude of laser return energy, is determined by combining slant depth and bottom level data recorded in the sounder data sets. This secondary "K" computation is displayed along with primary "K" for purposes of evaluating system response to the environment.

As data is read from tape during Pass 1, navigation data for Pass 2 is loaded directly on disk to reduce tape handling, and laser "on" times are stored on disk for later use in determining grid origin and track for grid.

The computed diffuse attenuation coefficient is sorted into three separate profiles. An average and a standard deviation is computed for each profile and portions of the profiles are displayed on the CRT.

Description of Algorithm and Comments:

Sounder data at the instant of the recorded waveform and sounder data immediately before and immediately after the waveform are examined to determine if a "K" computation is merited. If a "K" computation is merited the slope of the volume backscatter and a background level is computed from the digitized waveform.

5.1 SUBROUTINE INITIALIZE

Function:

Subroutine INITIALIZE asks the operator for details concerning the number of tapes to be processed, at what interval waveforms are to be displayed, the amount of delay (in "bins") required to model the HALS analog detection system, CFD, and threshold levels.

Description of Algorithm and Comments:

In an operational situation it is expected that only the number of tapes will change from mission to mission; therefore, only IEND is controlled by the operator.

5.2 SUBROUTINE REDAT

Function:

Subroutine REDAT reads the field recorded data tape, stores the information in their respective buffers, provides data sets for bias parameter processing when merited, passes navigation records on to disk, and prepares a laser "on/off" file.

Description of Algorithm and Comments:

Subroutine REDAT reads data from tape into a 6000 word buffer containing sounder data, which brackets the time slot of the digitized waveforms. The "real time" recorded for a specific waveform is used to find observation data (sounder data) at the same instant as the digitized waveform, and sounder observations before and after the waveform. Since the digitized waveform rate is dependent upon the laser scan rate, the quantity of waveforms recorded on tape will vary; therefore, the correlating sounder data may not be available within the sounder records immediately before and after the physical position of the waveform record on tape. REDAT continues to read and store relevant sounder data until a digitized waveform (2058) tape record is encountered. At the instant the waveform record is encountered, all prior available related sounder data has been stored. Since sounder data relating to the last

waveforms may be located physically on tape past the spot of the waveform, a counter "KK" is checked. When KK is less than four an additional sounder record is read and relevant sounder data stored. All additional required relevant sounder data will be available in the sounder tape record following the waveform record no matter what the sample rate.

5.3 SUBROUTINE HOLD

Function:

Subroutine HOLD finds sounder data before, at the instant, and after the instant of the digitized waveform and holds the data for further processing.

Description of Algorithm and Comments:

Subroutine HOLD triggers on bit number 6 of word 3 of sounder data. Bit 6 indicates the status of the Tektronix 7912 digitizer; when the bit indicates that Tektronix data is being collected, subroutine HOLD stores sounder data at that time for later use.

5.4 SUBROUTINE DISPLAY

Function:

Subroutine DISPLAY plots a time series of waveform data on the CRT at a rate established via subroutine INITIALIZE. A second data file is created from the exponentiated logarithmic waveform. This "linear" waveform is then scaled and displayed on the CRT; next the original logarithmic signal is scaled and plotted on the CRT and, finally, a "derivative" generated via a delayed subtraction of the lagged signal is displayed.

Description of Algorithms and Comments:

A linear waveform file is created by exponentiating the raw digitized waveform, which was quantized via the Tektronix 7912. The exponentiation is accomplished via a FORTRAN basic external computer function Z = EXP (Y).

A log derivative is formed by establishing a delay (DBIN) in terms of bins, then subtracting a delayed time series from itself, i.e., D(I) = W(I) - W(I-DBIN). The delay is established via the initialization subroutine. The time series are each scaled in subroutine WGRAPH.

5.5 SUBROUTINE WGRAPH

Function:

This subroutine computes the max and min values of a time series, scales each of the variables in the time series, drives the vector controlling the Graphic terminal and annotates the resultant display.

Description of Algorithm and Comments:

No scale is required for the X direction; the series X scale is implicit and ranges from 1 to 512. Y scale is limited to 400.

vs. change in amplitude of laser return energy, is determined by combining slant depth and bottom level data recorded in the sounder data sets. This secondary "K" computation is displayed along with primary "K" for purposes of evaluating system response to the environment.

As data is read from tape during Pass 1, navigation data for Pass 2 is loaded directly on disk to reduce tape handling, and laser "on" times are stored on disk for later use in determining grid origin and track for grid.

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A linear waveform file is created by exponentiating the raw digitized waveform, which was quantized via the Tektronix 7912. The exponentiation is accomplished via a FORTRAN basic external computer function Z = EXP (Y).

A log derivative is formed by establishing a delay (DBIN) in terms of bins, then subtracting a delayed time series from itself, i.e., D(I) = W(I) - W(I-DBIN). The delay is established via the initialization subroutine. The time series are each scaled in subroutine WGRAPH.

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Function:

This subroutine computes the max and min values of a time series, scales each of the variables in the time series, drives the vector controlling the Graphic terminal and annotates the resultant display.

Description of Algorithm and Comments:

No scale is required for the X direction; the series X scale is implicit and ranges from 1 to 512. Y scale is limited to 400.

5.6 SUBROUTINE MERIT:

Function:

Subroutine MERIT tests the slant depth, the energy level of the outgoing laser pulse, the energy level of the laser pulse return from the bottom, and the bottom return pulse width against a preset threshold. Failure of any one test will set a reject flag.

Description of Algorithm and Comments:

IVAL is set to one upon entering subroutine MERIT, IVAL is set to zero after failing any one test.

5.7 SUBROUTINE KSLOPE

Function:

Subroutine KSLOPE computes a diffuse attenuation coefficient (K) from the slope of the log of the volume backscatter, which was recorded in the digitized waveform. Slope, K, B/K, and average background level are sent to disk for use during Pass 3.

Description of Algorithm and Comments:

The following equations describe the relationship of the diffuse attenuation coefficient and the digitized volume backscatter.

$$I_2 = I_1 e^{-2K\,(D_2-D_1)}$$

therefore,

$$\frac{I_2}{I_1} = e^{-2K\,(D_2-D_1)}$$

$$\mathrm{Ln}\,\frac{I_2}{I_1} = -2K\,(D_2-D_1)$$

$$K = \frac{\mathrm{Ln}\,\dfrac{I_2}{I_1}}{-2\,(D_2-D_1)}$$

$$K = -\frac{1}{2}\,\frac{\ln I_2 - \ln I_1}{D_2 - D_1}$$

where:

I_1 = energy level near the sea surface,

I_2 = energy level just prior to the bottom pulse or somewhere downslope,

(D_2-D_1) = distance in meters between sea surface and latter pulse.

Since the HALS digitized waveform represents a signal already processed by a logarithmic amplifier, the digitized energy levels are actually $\ln I_1$, and $\ln I_2$.

5.8 SUBROUTINE NOISE

Function:

Subroutine NOISE computes the average and the standard deviation of a "derivative" computed from the digitized waveform. The values will be used for establishing noise level for other subroutines and displayed for evaluation purposes.

Description of Algorithm and Comments:

Noise average and standard deviation are computed for all bins beyond the surface peak. The derivative used has been computed in subroutine DISPLY.

5.9 SUBROUTINE KDIF

Function:

Subroutine KDIF provides a secondary "K", computed from the change in optical depth vs. change in amplitude of laser bottom return energy.

Description of Algorithm and Comments:

From the signal equation:

$$I_2 = I_1 e^{-2K(D_2-D_1)}$$

$$K = \frac{\ln (I_2/I_1)}{-2\ (D_2-D_1)}$$

or

$$K = \frac{\ln I_2 - \ln I_1}{-2\ (D_2-D_1)}$$

where, K is the diffuse attenuation coefficient,

I_1 is intensity of bottom return in shallow water,

I_2 is intensity of bottom return in deeper water,

D_1 is optical depth in shallow water,

D_2 is optical depth in deeper water.

The actual recorded HALS bottom levels are neither intensity I nor lnI, since the levels are the result of a logarithmic signal passed through a differencing circuit. However, this subroutine treats the levels as lnI.

5.10 SUBROUTINE SIMDEP

Function:

Subroutine SIMDEP simulates the operation of the HALS analog, real time detection circuit. The program operates on a "derivative" of the digitized waveform and computes a slant depth for comparison with the real time determined depth.

Description of Algorithm and Comment:

The differenced waveform is processed to determine the laser surface return peak; the leading edge of the surface return is then defined as the bin where the amplitude first exceeds 1.1 times the noise level. A trigger point is then set by combining the constant fraction discriminator value and the amplitudes of the leading edge and the peak of the surface return. A search for the bin where signal level just exceeds the trigger level sets the origin for the measurement. An approximation of the bottom peak is set by converting analog depth to bins and adding to the origin; the area is then searched for a bottom peak. Leading edge of the bottom return is "shallowest" bin, relative to the bottom peak, where the level still exceeds 1.1 times the average noise.

A trigger point is again set by combining a second constant fraction discriminator value and the amplitudes of the leading edge and peak of the bottom return. A search for the bin where signal level first exceeds the trigger level sets the bottom bin number. The difference between the surface bin and the botton bin numbers multiplied by the digitizer bin size equals the slant depth.

5.11 SUBROUTINE SWAP

Function:

Subroutine SWAP transfers sounder data into their respective lower order arrays and steps KK down appropriately. Subroutine SWAP is required to prevent loss of correlating sounder data, which may appear in a physical record after a digitized data record.

Description of Algorithm and Comments:

This is a bookkeeping routine.

5.12 SUBROUTINE SORT

Function:

At the end of Pass 1 subroutine SORT rewinds the output tape created via subroutine KSLOPE, and reads back the "K" value and relative position of the sample. Averages and standard deviation values are then computed relative to position to test homogeneity. Time series representing data left, center, and right are created and displayed via the CRT.

Description of Algorithm and Comments.

The "K" values are sorted via the correlating relative bearing data that was recorded along with the original sounder data. The test for homogeneity is merely an operator evaluation of adjacent averages and standard deviation. The CRT plot of the sorted "K" values represents only a sample of the available data.

5.13 SUBROUTINE ON

Function:

Subroutine ON establishes a file of time sequence laser on/off settings; the file is used in Pass 2 for establishing origin and track direction for the subsequent Grid processing in Pass 4.

Description of Algorithm and Comments:

Any time a 6000 word record is available the laser is "on." This subroutine initiates with the very first record in and then ends the sequence any time a time gap exists in the data.

6. NAVAID PROCESSOR

Function:

The NAVAID Processor performs the editing, position computation, and display for the HALS recorded NAVAID data. Editing is first performed on the individual time difference NAVAID data by detecting and removing "lane jumps" and "spikes." Positions are computed using an algorithm designed to handle either hyperbolic or range-range observation. The resulting positions are displayed on a screen for evaluation by the operator.

Description of Algorithm and Comments:

This algorithm orders the editing, position computation, and display of the navigation data. The operator interacts with the keyboard and display controlling the progress of the process. The operator may elect to display a range or range difference observation series for the purpose of detecting and removing land "jumps" and "spikes" in the data. When a jump is detected by the operator, a correction can be installed via the operator keyboard, and spikes are removed and replaced by an interpolated value. When the editing is completed, positions are computed and displayed in segments. When the operator determines that the plots are acceptable, the position information is stored on a disk for later interpolation and merging with laser data.

6.1 SUBROUTINE INITIALIZE

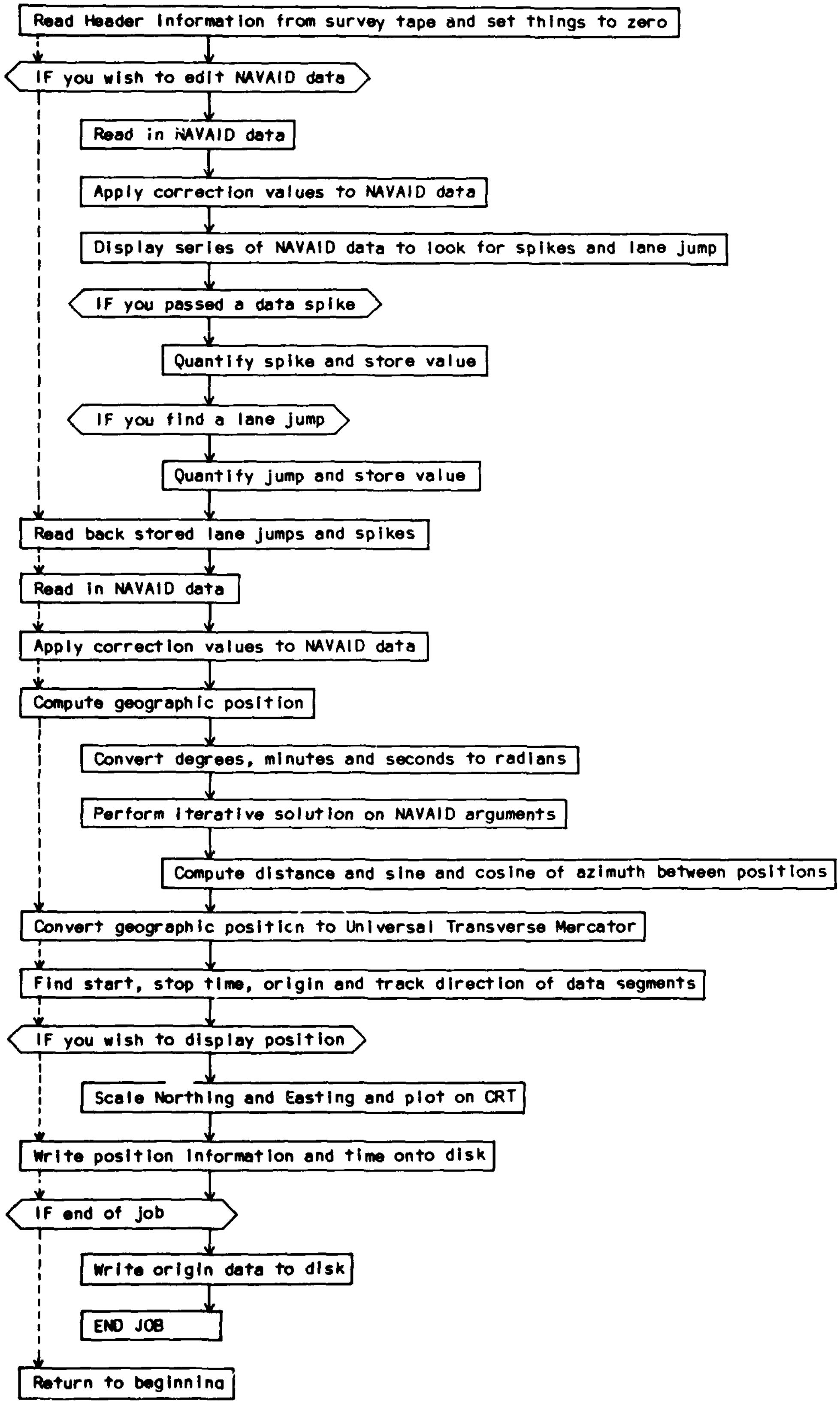
Function:

Subroutine INITIALIZE sets all things to zero, reads from Disk the header information containing the survey area coordinates, NAVAID station positions, survey lane list, and mission parameters and other premission data.

Description of Algorithm and Comments:

Program reads header data from Disk and sets variables to zero.

NAVAID PROCESSOR FLOW CHART



6.2 SUBROUTINE EDIT

Function:

The EDIT subroutine prepares a range or range difference observation series for display. The purpose of the display is to aid the operator in detecting "lane jumps" and data spikes. The EDIT subroutine selects (via operator) the Lines of Position which are to be operated on, orders the sequence of other subroutines, and interacts with the keyboard and display to isolate and prepare estimates of data spikes and lane jumps.

Description of Algorithm and Comments:

Taking an NSETS word time series representing an element of range or range difference NAVAID data and a time series representing "lane errors" and quality, this algorithm scales the data and displays the time series and the scale on the graphics display. An operator observes the display and decides if a spike or lane jump is present and, when necessary, enters via keyboard the approximate position of the spike or lane jump.

At a speed of 70 knots, observations will be spaced not more than 18 meters (m) apart. Lane width along with ARGO baseline is 93.6 m. A lane jump will appear at least five times a. large as normal position changes.

6.3 SUBROUTINE RETRVE

Function:

Subroutine RETRVE reads back the lane jump and spike correction data that has been stored via subroutine SAVE. Subroutines SAVE and RETRVE make it possible to create corrections on one run and then apply those corrections on a later run.

Description of Algorithm and Comments:

Performs unformatted read, may be used for additional tasks.

6.4 SUBROUTINE ARGOIN

Function:

Subroutine ARGOIN reads ARGO navigation records from disk and decodes the bit/byte arrangement to convert to words representing time differences, lane errors, and quality.

Description of Algorithm and Comments:

N/A

6.5 SUBROUTINE NORTEIN

Function:

Subroutine NORTEIN reads DELNORTE navigation records from disk and decodes the bit/byte arrangement to convert to words representing range measurements and station code.

Description of Algorithm and Comments:

N/A

6.6 SUBROUTINE SET

Function:

The SET subroutine applies correction values to the range or range difference NAVAID data.

Description of Algorithm and Comments:

This algorithm searches a time table established by subroutine JUMP and SPIKE to determine what correction to apply to the NAVAID range or range difference. The correction table is initially set to zero.

6.7 SUBROUTINE WITS

Function:

Subroutine WITS initializes the required parameters for subsequent computation of geographic position via subroutine FITS. The parameters include spheroid axes, flattening, eccentricity, transmitter station coordinates, antenna height, transmitter frequency, approximate initial position, and lane count or time difference observations.

Description of Algorithm and Comments:

The coding used for the NAVAID processing was acquired from NAVOCEANO in the form of the WITS program dated 15 May 1972. Subroutine WITS is a version of that same program but is modified to interface with the HALS system. The original WITS program can accommodate a large variety of combinations of NAVAID as can be seen from the documentation of the NAVOCEANO Computer Branch (1972). The HALS program can be modified to accommodate more NAVAID combinations using the same techniques if required.

6.8 SUBROUTINE GP2UTM

Function:

Subroutine GP2UTM converts geographic position (latitude and longitude) to Universal Transverse Mercator (UTM) grid coordinates. This program was supplied by NAVOCEANO and is slightly modified to interface with HALS post-processing.

Description of Algorithm and Comments:

This subroutine accepts as input the semi-major and semi-minor spheroid axes in meters, the central meridian in radians of the UTM zone in which the computations will be made, and the latitude and longitude of the point to be computed in radians (using the sign convention of positive latitudes in the northern hemisphere and positive longitudes west of the Greenwich meridian). The program outputs the northing and easting of the point in meters on the UTM grid.

This subroutine does not attach the false northing of 10^7 to the northings in the southern hemisphere. Thus, the northing of a point 10 m south of the equator would be -10, that of a point 5,000,000 m south of the equator is -5,0000,000. Thus, coordinates yielded are ordinary rectangular coordinates with no sudden jump at the equator. This is useful if the UTM's are used as the basis of plotting coordinates when the plot may be required to cross the equator. The false northing artifice can be reinstated by removing the comments from the FORTRAN coding.

6.9 SUBROUTINE DISPLA

Function:

Subroutine DISPLA prepares a graphic plot of the position information computed for each segment of NAVAID data.

Description of Algorithm and Comments:

Graphic work space is 520 pixels wide (easting) and 420 pixels high (northing).

6.10 SUBROUTINE JUMP

Function:

Subroutine JUMP "looks" for a lane jump near the area designated by the operator and, upon finding the largest step within a specified span, computes a new lane correction and the time of occurrence.

Description of Algorithm and Comments:

The algorithm computes the magnitude of a derivative of ten elements of a series. The largest derivative is designated the lane jump, and its value is added to a lane correction series. The derivative steps are computed as an integer to correspond with whole lane jumps.

6.11 SUBROUTINE SPIKE

Function:

Subroutine spike tests a time series for an unusually large data variation and, where one occurs, stores a replacement observation with a value derived from two adjacent observations.

Description of Algorithm and Comments:

A derivative series is computed from consecutive NAVAID observations; the standard deviation of the derivative series is then determined. The derivatives for pairs of observations are compared with the standard deviation and rejected if greater than a four sigma level.

6.12 SUBROUTINE SAVE

Function:

Subroutine SAVE stores lane jump corrections and time of corrections for later use in the event that program NAVAID is executed without a call to subroutine EDIT. SPIKE time and replacement values are also stored.

Description of Algorithm and Comments:

Not necessary.

6.13 SUBROUTINE DRAW

Function:

Subroutine DRAW computes the max and min values of three separate time series, scales the series for display, drives the vector controlling the graphic terminal for three adjacent displays and annotates the screen with values describing each time series.

Description of Algorithm and Comments:

Graphic work space is 520 pixels wide (X) and 420 pixels high (Y). Range or range difference data is scaled to fill a pixel area 520 wide by 390 high. Lane error is scaled to fill a pixel area 520 wide by 20 high. Quality designators are scaled to fill a pixel area 520 wide by 10 high. The display area is filled regardless of the number of data sets (NSETS) available from NAVAID record.

6.14 SUBROUTINE FITS

Function:

This routine takes all the information input in WITS (station positions, lane widths, coding delays, antenna height, and lane counts) and computes the geographic position, using an iterative method described above. All arguments are transferred via COMMON. Computations are done in double precision.

Description of Algorithm and Comments:

The coding used is part of the WITS program acquired from NAVOCEANO; the only changes convert the common statement to a labeled common statement and a data statement is substituted for setting some elements to zero. Details of the algorithm are covered in subroutine WITS (6.7).

6.15 SUBROUTINE DINV

Function:

Subroutine DINV is an integral part of the WITS program. The subroutine computes the distance and sin and cos of the azimuth (from south) between two geographic positions. All arguments and computations are performed in double precision. Uses Sodano inverse formulas.

Description of Algorithm and Comments:

The FORTRAN coding is part of the WITS program acquired from NAVOCEANO; no changes have been made to the code. The algorithms are described in detail in NAVOCEANO Computer Branch (1972).

6.16 SUBROUTINE DRDO

Function:

Subroutine DRDO converts degrees, minutes, and seconds of latitude or longitude to radians.

Description of Algorithm and Comments:

This is a subprogram of the WITS program acquired from NAVOCEANO. The subroutine has not been altered.

6.17 SUBROUTINE ORGIN

Function:

Subroutine ORGIN sets up data segments for the (Pass 4) grid process. The grid represents a swath nominally 1200 feet wide and 12000 feet long, aligned along the aircraft flight path. The aircraft will "fly" within the grid and acquire observations covering a swath approximately 700 feet wide or less. This program sets up a start time, a stop time, an origin, and track direction for each segement.

Description of Algorithm and Comments:

Subroutine ORGIN reads, via an unformatted read from disk, data describing laser on/off intervals and, in conjunction with distance along track computed via the northing and easting supplied by the NAVAID processor, sets up segments of data that can be handled via the GRID processor during Pass 4. The segments are limited in size because of CORE requirments during Pass 4.

7. ATTALT PROCESSOR

Function:

The ATTALT (altitude, attitude) processor uses slant range laser measurements from aircraft to sea surface for the purpose of estimating altitude, pitch, roll, and waves. The estimated pitch and roll is compared with vertical gyro data and is displayed for evaluating overall system performance. Calculated ranges are compared with observed ranges for editing and rejection purposes. Slant depth is corrected for environmental bias and wave error, then combined with positions information and direction cosines to compute depth and assign location for each laser sounding.

Descripton of Algorithm and Comments:

The algorithm for tracking altitude, attitude, and waves is an optimal filter.

Recrusive equations:

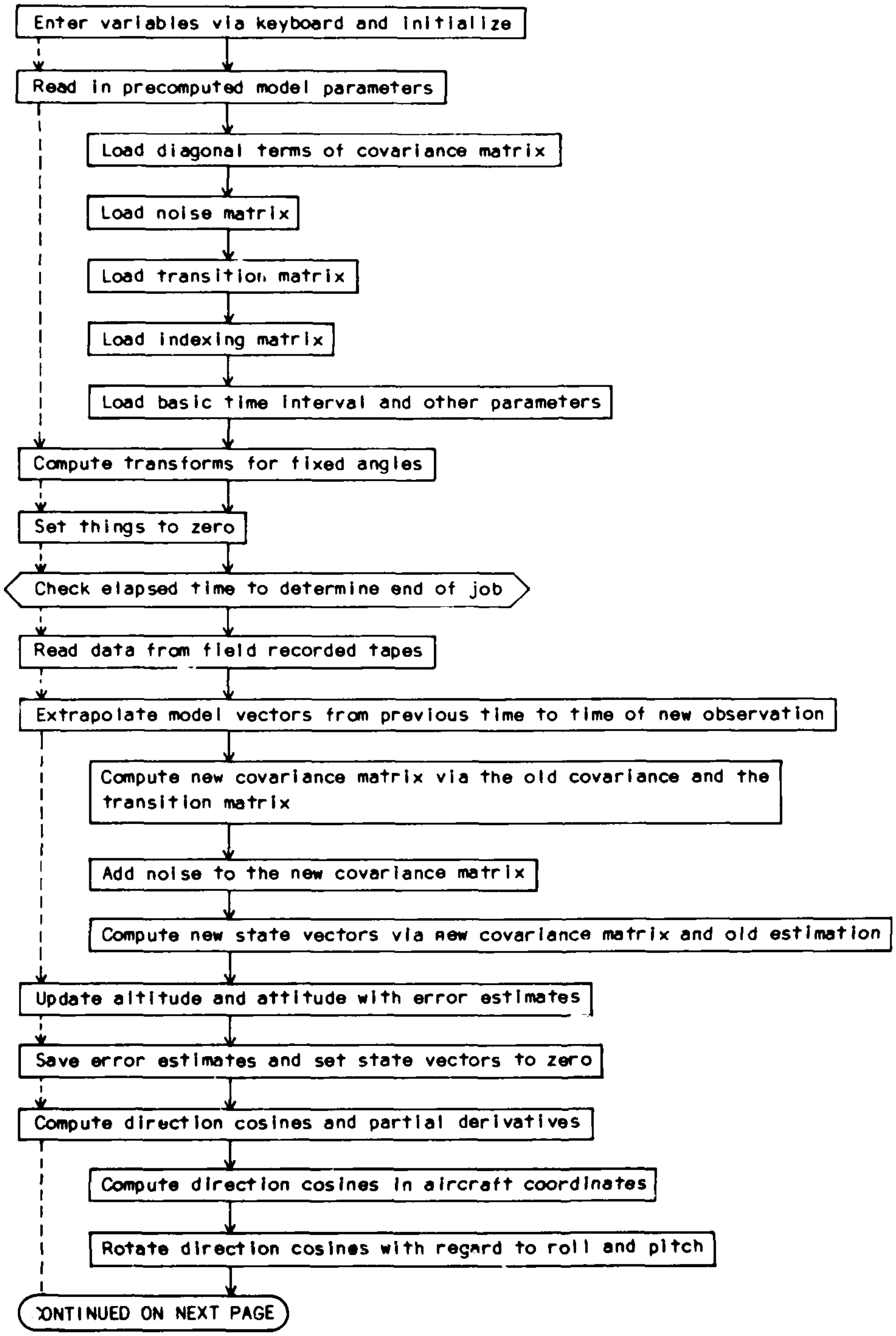
$$K(ti)=P(ti-o)\ M^T(ti)\ (M(ti)P(ti-o)M^T(ti))^{-1}$$

$$P(ti+o)=(I-K(ti)M(ti))P(ti-o)$$

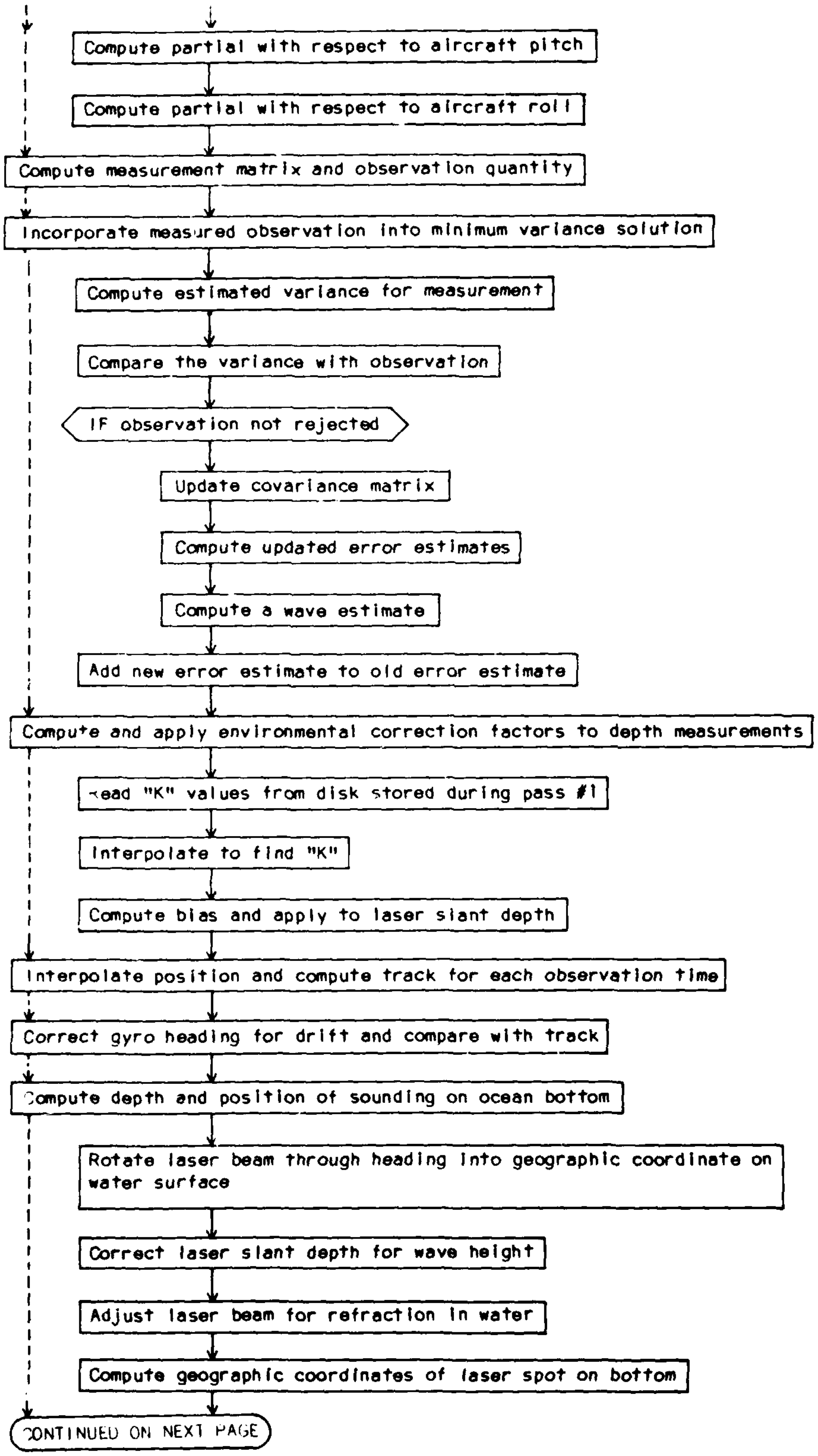
$$\hat{X}(ti+o)=\hat{X}(ti-o)+K(ti)(Y(ti)-M(ti)\hat{X}(ti-o))$$

are extrapolated at intervals of 1/400 second and updated with each laser observation supplied at any interval. In the Matrix equations:

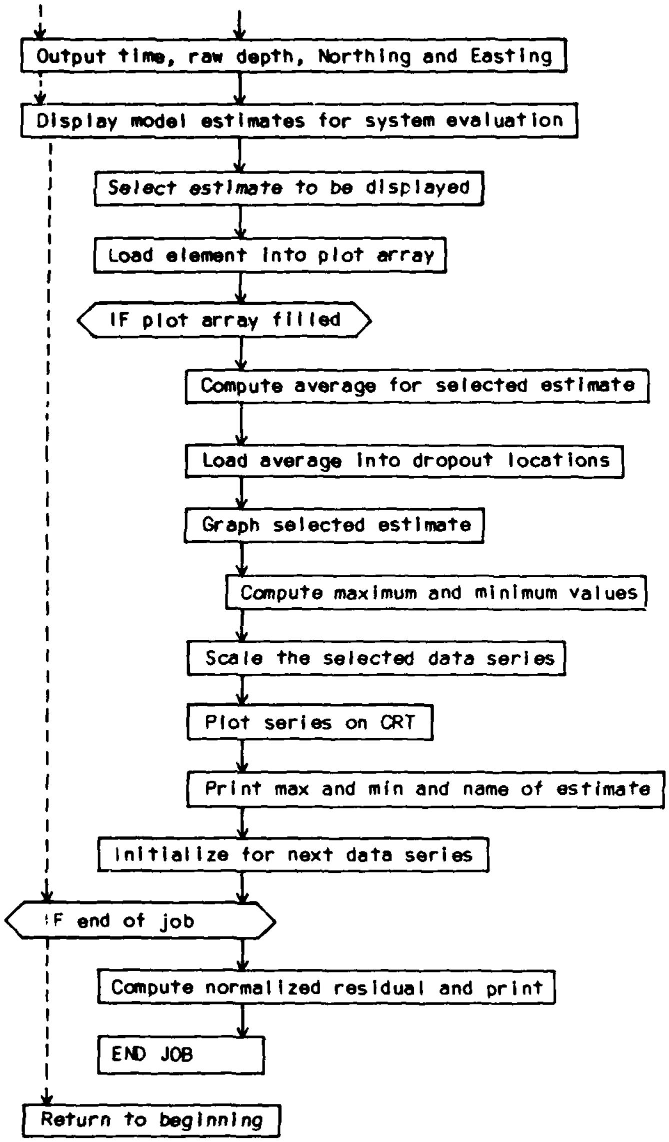
ATTALT PROCESSOR FLOW CHART



ATTALT PROCESSOR FLOW CHART (Continued)



ATTALT PROCESSOR FLOW CHART (Continued)



Y(ti) is the observation matrix at time "ti"

P(ti) is the covariance matrix

M(ti) represents the linear combination of the measurement

X(ti) state vectors representing roll, pitch, or altitude at time "ti"

K(ti) is a weighting matrix.

I is an identity matrix.

The above general equations are adapted to the specific problem of altitude, attitude, and waves via the modeling described by Fagin Associates (1979). The modeling establishes the observation matrix Y(ti) as the difference between the observed laser slant range from aircraft to sea surface minus a slant range computed from estimates of altitude and attitude. The measurement matrix M(ti) is composed of the partial of true slant range with respect to the partials of aircraft altitude, aircraft pitch, and aircraft roll. The covariance matrix P(ti) contains the predicted error at any time for any component pitch, roll, and altitude. The state vectors X(ti) are modeled with slowly changing rates and as such are distinguished from a wave which is assumed to be random. The calculation $M(ti)P(ti)M^T(ti)$ predicts the absolute magnitude of the observation Y(ti); when the observation exceeds 2.5 times that prediction, the observation is rejected. The observations incorporated into the solution are further evaluated via a normalized residual, which indicates how well the incorporated data fit the model. The normalized residual results from the square root of an average of the observation squared divided by $M(ti)P(ti)M^T(ti)$; the results equal 1.0 when the data agrees with the model; when results are less than 1.0, the model is pessimistic, i.e., the data is better than the prediction when results are greater than 1.0 and vice versa.

7.1 SUBROUTINE READRANGE

Function:

Subroutine READRANGE reads the field-recorded data tape, stores the information in the laser data buffer, and provides a data set of slant range, pitch, roll, heading, relative bearing, time, and laser slant depth on request from the main program. The subroutine looks for end of tape, rewinds and mounts next tape, provides a flag when all mission tapes are completed, and rejects on low laser energy. The system also selects depth from pulse width or slant depth and rejects on the basis of bottom level alone when slant depth has been selected as the observation.

Description of Algorithm and Comments:

Word 5, bits 8 through 15, representing underwater range, can appear as four different conditions: (1) a valid observation of underwater range; (2) a noise spike; (3) a times out or maximum depth quantity, indicating that a second pulse has not been detected because the depth is beyond the HALS capability; and (4) a times out, indicating no second pulse because the water is shallow. Conditions (1) and (2) are tested for the amplitude of the bottom pulse, and, if greater than an established quantity, word 5 is used as the observation. When bottom pulse amplitude is low or when conditions 3 or 4 are encountered, width of the surface pulse is tested via word 4. When surface pulse width is approximately equal to or less than the laser input pulse, deep water is assumed and the observation is rejected if a times out has occurred.

7.2 SUBROUTINE EXTRAP

Function:

Subroutine EXTRAP extrapolates the covariance matrix and the error estimates for each 1/400 second time interval. The extrapolation utilizes the transition matrix and the Q matrix established via a previously exercised Initialization Program.

Description of Algorithm and Comments:

Extrapolation is accomplished as follows:

$$\hat{X}(ti+1) = \Phi \hat{X}(ti+o)$$

$$P(ti+1) = P(ti+0) + \Phi P(ti+o)\Phi^T + Q$$

where

$\hat{X}(ti)$ and $P(ti)$ are described in section 7.

Φ is the transition matrix established by Program Initialize

Q is the noise matrix established by Program Initialize

In the interest of computational efficiency the actual coding of the subroutine has been rearranged avoiding multiplication by zero.

7.3 SUBROUTINE FNDRNG

Function:

Subroutine FNDRNG computes the direction cosines for position determination and the partial derivatives which are used in the measurement matrix.

Description of Algorithm and Comments:

Coordinate transformations and derivations are described by Fagin Associates (1979).

Direction cosines in aircraft coordinates

$$S_x' = -.70711 \,(2 \sin a \cos a \sin \gamma + 2 \sin^2 a \sin \gamma \cos \gamma)$$

$$S_y' = 2 \sin a \cos a \cos \gamma - \sin^2 a \sin 2\gamma$$

$$S_z' = \cos^2 a - \sin^2 a \cos^2 \gamma$$

Roll rotation

$$S_x''' = S_x'$$

$$S_y''' = S_y' \cos(\text{roll}) - S_z' \sin(\text{roll})$$

$$S_z''' = S_z' \cos(\text{roll}) + S_y' \sin(\text{roll})$$

Pitch rotation

$$S\overset{''}{x} = S\overset{'''}{x} \cos(\text{Pitch}) - S\overset{'''}{z} \sin(\text{Pitch})$$

$$S\overset{''}{y} = S\overset{'''}{y}$$

$$S\overset{''}{z} = S\overset{'''}{z} \cos(\text{Pitch}) - S\overset{'''}{x} \sin(\text{Pitch})$$

Partials with respect to pitch in direction cosines

$$\frac{\overline{S}xg}{(\theta)} = S\overset{''}{z}$$

$$\frac{\overline{S}yg}{(\theta)} = 0.0$$

$$\frac{\overline{S}zg}{(\theta)} = -S\overset{''}{x}$$

Partials with respect to roll in direction cosines

$$\frac{\overline{S}xg}{(PHI)} = 0.0$$

$$\frac{\overline{S}yg}{(PHI)} = S\overset{'''}{z}$$

$$\frac{\overline{S}zg}{(PHI)} = S\overset{'''}{y}$$

Partials with respect to heading in direction cosines

$$\frac{\overline{S}xg}{(Hdg)} = Sy \sin(\text{Pitch})$$

$$\frac{\overline{S}yg}{(Hdg)} = -S\overset{'''}{z}$$

$$\frac{\overline{S}zg}{(Hdg)} = S\overset{'''}{y} \cos(\text{Pitch})$$

a is angle between normal to mirror and its axis of rotation

γ is phase angle of mirror rotation

7.4 SUBROUTINE MEAS

Function:

Subroutine MEAS is used to incorporate data into the solution when the data passes the rejection test. When incorporating data, the covariance matrix is updated, new error estimates are computed, and wave height is derived.

NOTE: Transformation into local geographic coordinates occur in subroutine MIX.

Description of Algorithm and Comments:

Subroutine MEAS executes the equation described in section 7. The order of execution is not precisely as described in the equations because of attempts at computational efficiency. Wave height is defined as:

$$W = -SGMS*Y(ti)/M(ti)P(ti)M^T(ti)$$

where:

SGMS is the *a priori* sigma of wave height

Y(ti), M(ti), and P(ti) are as described in section 7.

W is wave height

7.5 SUBROUTINE INPUT

Function:

Subroutine INPUT provides access by the operator via the keyboard to enter the amount of survey time to be processed, off NADIR angle, sigma of the wave heights encountered, the sigma of the slant range to surface measurement, tide, and the average altitude. This subroutine replaces the card input indicated in Fagin Associates (1979).

Description of Algorithm and Comments:

Subroutine INPUT provides a query to the operator via the graphic display. The operator responds by keying in required data. Data is transferred internally via IARR, and RARR both in common.

7.6 SUBROUTINE RDTP

Function:

Subroutine RDTP orders the initializing procedure and accepts data via common transfer to initialize the covariance matrix P(ti), the noise matrix Q, the transition matrix Φ, and the indexes.

Description of Algorithm and Comments:

Subroutine sets data into arrays for initialization of ATTALT.

7.7 SUBROUTINE RWRT

Function:

Subroutine RWRT reads an unformatted tape and sets up an array in common for transfer of the data for initialization. This subroutine operates on real numbers.

Description of Algorithm and Comments:

None required.

7.8 SUBROUTINE RINDX

Function:

Subroutine RINDX reads integer values from an unformatted tape and initializes an index array. The index array is for avoiding multiplication by zero.

Description of Algorithm and Comments:

The index array was established via an initialization program; the purpose of the array is to increase efficiency by avoiding multiplication by zero.

7.9 SUBROUTINE SOUNDER

Function:

Subroutine SOUNDER uses environmental water quality data generated during Pass 1 and, with data relative to incidence angle, computes and applies a bias correction factor.

Description of Algorithm and Comments:

The equation for the bias corrector has been developed as the result of a regression analysis on bias predictions produced via a Monte Carlo simulation.

7.10 SUBROUTINE NAV

Function:

Subroutine NAV takes navigation fix information from Disk, which was produced via Pass 2, and provides an interpolation of position for each basic time interval between fixes and computes track.

Description of Algorithm and Comments:

First time into subroutine, ATIME, ALAT, ALONG, BTIME, BLAT, BLON are all read from disk; after initial read INITO is set equal to one and prevents further reads from disk upon entry. Additional reads are accomplished when indicated time exceeds (BTIME). Track angle is the arc tangent between two successive NAVAID fixes.

7.11 SUBROUTINE MIX

Function:

Subroutine MIX takes interpolated navigation data from subroutine NAV and mixes it with altitude and laser direction cosine estimates to compute depth and assign location for each laser sounding on the ocean bottom.

Description and Algorithm Comments:

Subroutine MIX rotates direction cosines of the laser beam in local aircraft coordinates through heading into local geographic coordinates and computes the position of the laser spot on the water surface relative to the aircraft.

$Sxg = S'x \cos (Hdg) - S'y \sin (Hdg)$

$Syg = S'y \cos (Hdg) + S'x \sin (Hdg)$

$Szg = S'z$

Δ LAT = (Altitude/szg) sxg

Δ LON = (Altitude/Szg) Syg

Direction of the beam is adjusted for refraction in water using Snell's law, and position on bottom relative to surface spot is computed after correcting slant depth for wave height

Refracted Sxg = Sxg/1.33

Refracted Sgy = Sxg/1.33

Refracted Szg = $((1.33)^2 - 1.0 + Sz^2)/(1.33)^2$

Δ LA = Slant Depth/Sxg (Refracted)

Δ LO = Slant Depth/Syg (Refracted)

Vertical Depth = Slant Depth/Szg (Refracted)

Geographic coordinates of laser spot on bottom is:

Latitude = LAT + Δ LAT + Δ LA

Longitude = LON + Δ LON + Δ LO

where: LAT and LON are geographic coordinates of aircraft. Positions are actually in UTM coordinates via Pass 2 (NAVAID Processor)

7.12 SUBROUTINE DISPLAY

Function:

Subroutine DISPLAY selects a sequence of data from altitude, wave height, estimated roll, estimated pitch, instrumented roll, instrumented pitch, or gyro drift and stores it for subsequent plotting on the CRT. The subroutine fills missing elements with a computed average of the sequence.

Descripton of Algorithm and Comments:

Algorithm selects a 400 observation sequence and prepares a display that resembles a time series plot. The algorithm selects every tenth observation from the first 4000 to prepare a coarse plot. The program then plots the next 400 observations as a fine plot. The algorithm continues to cycle in the above fashion through all the indicated parameters.

The purpose of the fine plot is to observe any oscillation that correlates with the sweep frequency of the laser scanner. A large amplitude in the oscillation may indicate a system misalignment.

The coarse series is intended to provide the operator a means to evaluate system performance over longer term. The observations relating to the optimal estimates, displayed here, are the results of laser slant range measurements that have been incorporated into the minimum variance solution: laser slant range measurements that have been rejected have no effect on the display.

7.13 SUBROUTINE OUTPUT

Function:

Subroutine OUTPUT loads time, northing, easting, and depth into a 6000 word buffer. When the buffer is full, the buffer contents are transferred to disk; at the end of the mission the disk contents are copied on magnetic tape.

Description of Algorithm and Comments:

The buffer holds 6000 words, and each observation requires four double-precision words or eight (16 bit) words total. Therefore, the buffer can accumulate up to 750 observations before transferring to disk. When the mission processing has been completed, the disk contents are copied on magnetic tape.

7.14 SUBROUTINE HEADING

Function:

Subroutine HEADING corrects heading for drift and then compares heading with track for purposes of preparing a display that will aid in evaluating gyro performance. Drift must be interpolated prior to applying to Heading.

Description of Algorithm and Comment:

Heading variations or noise are not yet determined. A filter may be required.

7.15 SUBROUTINE GRAPH

Function:

Subroutine GRAPH computes the MAX and MIN values of a time series, scales the series for display, drives the vector controlling the graphic terminal, and annotates the screen with values describing the time series.

Description of Algorithm and Comments:

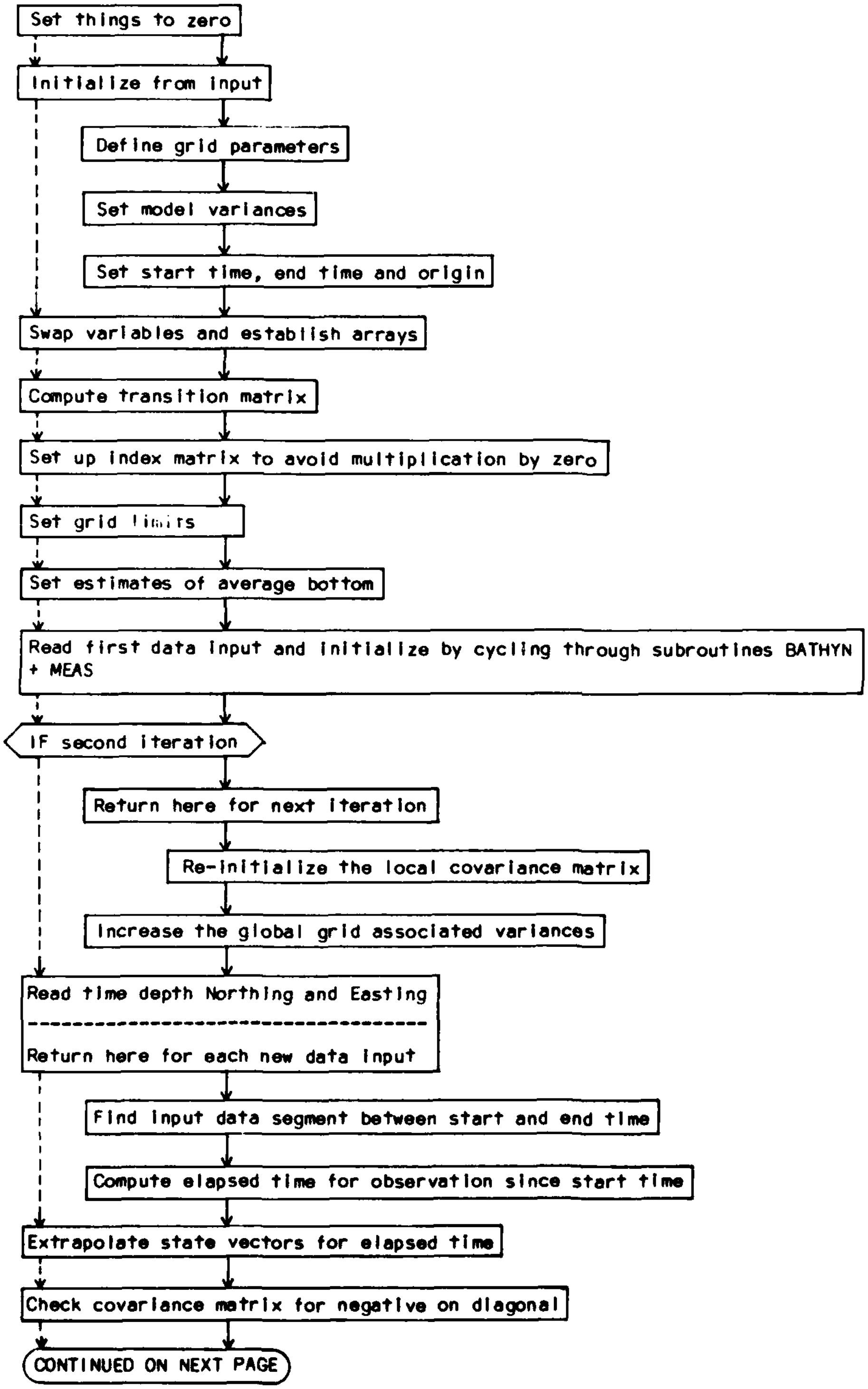
Graphic work space is 400 pixels wide (x) and 420 pixels high (y). The data series is scaled to fill 400 pixels high (y). The width (x) of the display requires no scale since the series is always 400 elements long.

8. <u>GRID PROCESSOR</u>

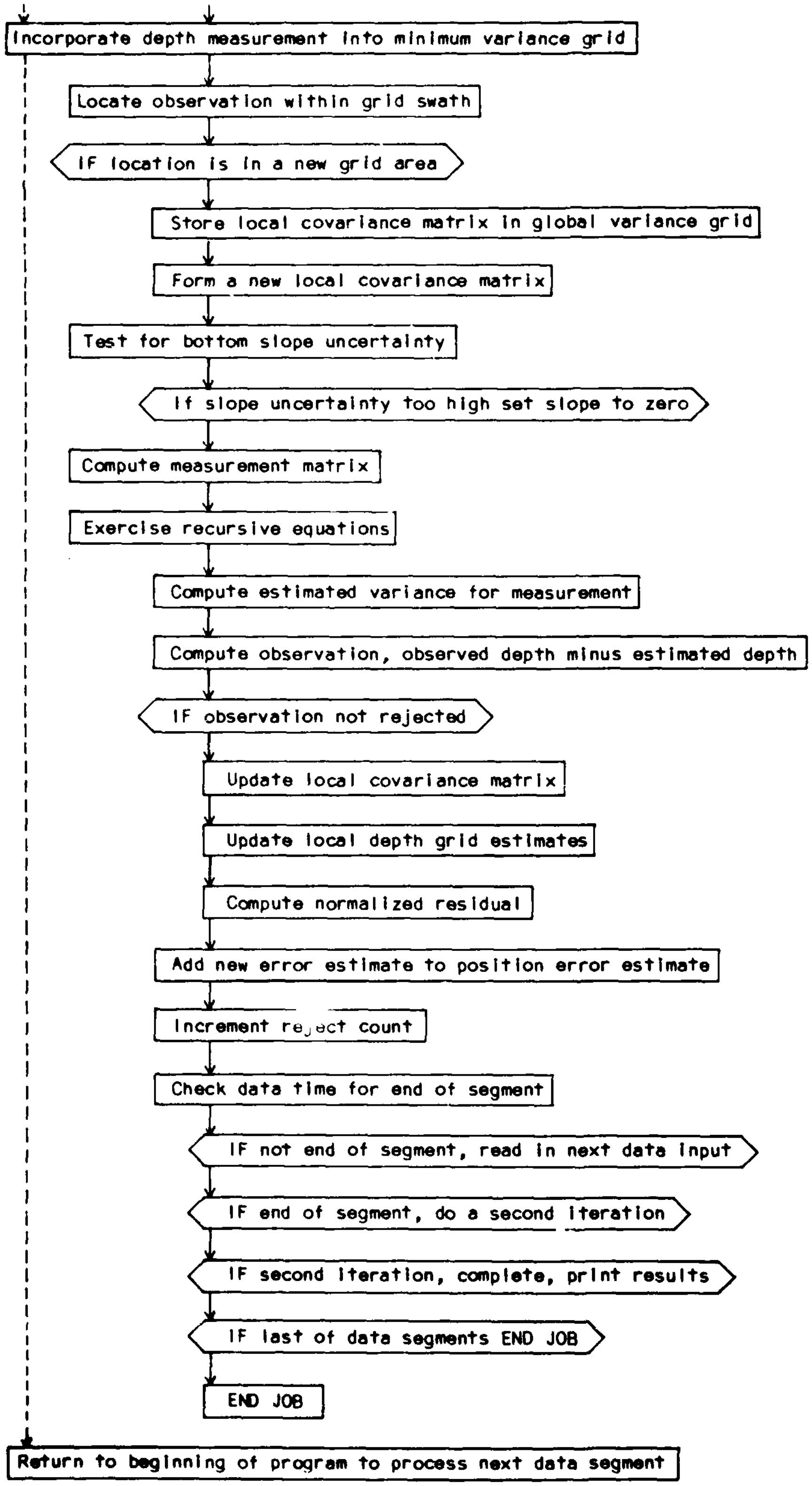
Function:

This program uses inputs of position, depth, and time from tape or disk generated via ATTALT to produce a minimum variance grid of depth estimates. The program accepts dense noisy depth and position information and produces a sparse grid

GRID PROCESSOR FLOW CHART



GRID PROCESSOR FLOW CHART (continued)



wherein data ambiguity has been reconciled. The process incorporates or rejects laser depth observations on a statistical basis, taking into account bottom slope, positioning accuracy, and depth measurement accuracy all simultaneously. The process also weights data in favor of shallowest depth so that a peak lying between grids will force a bias toward the shallower depth.

Description of Algorithm and Comments:

The Grid program executes the same recrusive equations shown in section 7. Those equations are:

$$K(ti) = P(ti-o)M^T(ti)\ (M(ti)P(ti-o)M^T(ti))^{-1}$$

$$P(ti+o) = (I-K(ti)M(ti))P(ti-o)$$

$$X(ti+o) = X(ti-o)+K(ti)(Y(ti)-M(ti)X(ti-o))$$

However, the modeling as described by Fagin Associates (1979) is different from that used in ATTALT. The observation $Y(ti)$ is modeled as the difference between measured depth and a depth calculated from a current grid of depth estimates. The measurement matrix $M(ti)$ is composed of the partials of depth with respect to position and the locations of the four grid depths surrounding the location of the observation. The state vectors $X(ti)$ are modeled as the error in position and estimates of depth at the grid points. Both the covariance matrix $P(ti)$ and the estimates $X(ti)$ are limited to six "local" states, and are interchanged with a large holding array representing a grid over the survey swath. The calculation $M(ti)P(ti)M^T(ti)$, just as in program ATTALT, is used to reject or incorporate data. The normalized $((Y(ti))^2/(M(ti)P(ti)M^T(ti)))$ residual is calculated in the same way as in ATTALT and has the same meaning. Ocean bottom slope enters the process in two different ways (1) as an <u>a priori</u> description introduced as "variance of depth differences" (or depth difference between adjacent grid points), and (2) as a moderator on position uncertainty introduced via the measurement matrix. Generally in an operational mode the process will be iterated a second time so that bottom slope will be less uncertain. The second iteration reevaluates the original data by performing the same operations as in the first pass. Prior to the iteration, all the model variances are degraded by a fixed amount, but the estimates are retained as they were calculated at the end of the first pass. A bias relative to shallowest depth is introduced via subroutine MEAS during computation of $M(ti)P(ti)M^T(ti)$. Prior to computation of MPM^T the variance of the depth measurement is altered in proportion to the square root of the actual depth encountered. Since the alteration takes place before evaluation, the bias has a two-fold effect; (1) there is less likelihood of rejecting shallower data; and (2) when incorporated, the shallow depth has more influence on the depth estimates than the deeper depth.

8.1 SUBROUTINE INPUT

Function:

Subroutine INPUT provides access by the operator via the keyboard to enter the initialization data required for defining the grid parameters and variances of data input. The operator can influence results by designating position accuracy, bottom slope, and measurement accuracy. Data for origin and track are carried over from Pass 3 subroutine ORGIN.

Description of Algorithm and Comments:

The operator may vary a priori position accuracy depending on NAVAID employed. Short range navigation would usually indicate a lower variance than medium range hyperbolic; likewise, the operator may wish to change variance depending on the location of the survey within the NAVAID net. Variance in depth measurement accuracy can be related to the average D encountered. Variance of depth difference relates to the difference between two adjacent grid estimates and, for a given grid spacing, determines bottom slope.

8.2 SUBROUTINE PHICMP

Function:

Subroutine PHICMP computes the transition matrix Φ using model information established by subroutine input.

Description of Algorithm and Comments:

This subroutine is executed only once at the beginning of the Grid process. The resulting transition matrix is used by subroutine EXTRP. $\Phi(ti+s;ti)$, the state transition matrix, is determined as the solution of the matrix differential equation.

$$\frac{d\Phi(ti+s,ti)}{ds} = A(ti+s)\,\Phi(ti+s,ti)$$

initially $\Phi(ti,ti) = I$

ti is the observation time

s is some time increment less than the observation interval

I is an identity matrix

A(ti) is a KbyK "system" matrix which may vary with time, established by subroutine INPUT

8.3 SUBROUTINE QCOMP

Function:

Subroutine QCOMP computes a noise matrix that is added to the covariance matrix during extrapolation.

Description of Algorithm and Comments:

Subroutine QCOMP is executed only once at the beginning of the Grid process. Results from QCOMP are stored in the Q matrix for later use by subroutine EXTRP. Values are determined by $Q(ti+s) = \Phi(ti+s,ti)\int_0^s \Phi^{-1}(ti+t;ti)\, q(ti+t)$

$\Phi^{-it}(ti+t;ti)dt\, \Phi^{T}(ti+s;ti)$

where:

$q(t) = \pi\delta(t_1 - t_2)\ q(t_1)$

$q(t_1)$ is established via subroutine INPUT

$\Phi(ti)$ is as computed in subroutine PHI

δ is a dirac delta function

ti is an observation time

s is a small time increment less than the observation interval

Subroutine INPUT establishes (ti), which directly affects the computation of the Q matrix, thereby adjusting the noise level to the local environment.

8.4 SUBROUTINE READEP

Function:

Subroutine READEP loads 6000 word records from tape or disk, created during Pass 3, into the buffer. Then, the program searches for the beginning time segment of a data swath, which was defined by subroutine ORGIN. After finding the correct time segment of data, the subroutine returns one observation of time, depth, northing, and easting for each call to the routine.

Description of Algorithm and Comments:

The indicated time (INDTN) is the elapsed time from the start of the grid segment. The start time was defined in subroutine ORGIN during Pass 2.

8.5 SUBROUTINE BATHYN

Function:

Subroutine BATHYN locates the observation within the grid, computes the measurement matrix, and adjusts the depth estimates and variance as new grid sections are encountered.

Description of Algorithm and Comments:

Location of the observation within the grid is established by the subscripts (or indexes) K and L, which are a function of the position of the observation relative to the grid origin and the spacing between grids. The measurement matrix partials with respect to position are obtained from the slope between adjacent grid intersections. The slope is set to zero when fewer than six observations have been incorporated into the surrounding grid estimates. Also, the slope is set to zero when the slope uncertainty exceeds the calculated slope. Subroutine BATHYN sets up a quasi measurement matrix and calls subroutine MEAS when encountering new grid intersections; the "new" variances and estimates are adjusted relative to "old" values by the "variance of depth difference" which was inserted via subroutine INPUT.

8.6 SUBROUTINE MEAS

Function:

Subroutine MEAS is used to incorporate data into the solution when the data passes the rejection test. As the data is incorporated the covariance matrix is updated, and new depth estimates are computed within the "local" grid.

Description of Algorithm and Comments:

Subroutine MEAS executes the equations described in section 8. The subroutine is similar to the subroutine MEAS described in Pass 3 but has been modified specifically for program Grid. In addition to incorporating depth observation, subroutine MEAS performs the function of adjusting variances and grid estimates via the variance of depth differences as new sections of grid are encountered. Subroutine MEAS executes in the following sequence with each new observation:

(1) compute MPM^T,

(2) adjust measurement accuracy for depth and add to MPM^T,

(3) evaluate by comparing MPM^T with observation,

(4) update the local covariances,

(5) propagate the observation to depth estimates and position error,

(6) compute the normalized residual to determine how well data fits model.

8.7 SUBROUTINE EXTRAP

Function:

Subroutine EXTRAP extrapolates the covariance matrix and error estimates for each 1/400 second time interval. The extrapolation utilizes the transition matrix computed in subroutine PHI and the Q matrix established via subroutine QCOMP.

Description of Algorithm and Comments:

Same as 7.2 of Pass 3.

8.8 SUBROUTINE OUTPUT

Function:

Subroutine OUTPUT arranges the printout of depth estimates, covariance, and rejects in a manner that will aid the hydrographer in evaluating the final data output. The subroutine produces printed depth values in adjacent strips of depth, covariance, and rejects. The hydrographer can select, from the printout, a depth value at any grid point and then, by looking at the adjacent printout on the same page, find the correlating quality indicator and in a third column of printout find the data rejection rate for that area.

Description of Algorithm and Comments:

The printout presents data arrays from which a hydrographer selects soundings for manually plotting on a hydrographic smooth sheet. The data arrays are also output to magnetic tape for archival and to facilitate automated version of data plot.

REFERENCES

1. Guenther, G. C. and R. W. Thomas (1981). Monte Carlo Simulations of the Effects of Underwater Progagation on the Penetration and Depth Measurement Bias of an Airborne Laser Bathymeter. NOAA Technical Memorandum OTES 01, Rockville, Md., 144 p.

2. NAVOCEANO Computer Branch (1972). WITS Program Documentation. Naval Oceanographic Office, NSTL Station, Miss.

3. S. L. Fagin Associates (1979). HALS Shipboard Survey Processor. Prepared for Naval Oceanographic Office, Contract no. N68463-78-C-0041.

4. Byrnes, H. J. and S. L. Fagin (1978). Optimal Filtering and Analysis of Scanning Laser Data. NORDA Technical Note 24, NSTL Station, Miss, 20 p.

5. Byrnes, H. J. (1979). Operating Scenario for a Hydrographic Airborne Laser Sounder. NORDA Technical Note 34, NSTL Station, Miss, 30 p.

APPENDIX

Available under separate cover are limited quantities of below listed auxiliary documents; interested parties may receive a copy upon request to NORDA Code 370.

A. <u>FORTRAN Code for HALS Post Processing</u>

Contains a listing of the computer programs implementing the software design. The FORTRAN code is generously laced with comments describing the functions of each routine, the definition of the variables and restrictions and limitations.

B. <u>Data File Documentation for HALS Post Processing</u>

Describes each of the files created while exercising each of the four main processors.

C. <u>Users Guide for Exercising HALS Post Processing Software</u>

Provides a "walk through" cook book type guide with step by step displays of operator action and computer reaction while exercising the software via simulation survey data file.

D. <u>HALS Post Processing Software Test Plan</u>

Discusses test strategy for higher order testing and describes procedures for exercising all code options or decision paths within the HALS post processing computer code to insure that each processing module is functioning as intended.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report discusses software that was designed and developed to process Hydrographic Airborne Laser Sounder (HALS) data tapes. The HALS survey produces tapes containing navigational, heading, altitude, and various house-keeping information, as well as raw laser ranging data from which ocean depths are to be extracted in a post-mission processing mode.

The software performs its tasks in four sequential processing passes. During Pass 1 (WAVEFORM processor) optical properties of water in the Survey area

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are quantized and evaluated; during Pass 2 (NAVAID processor) navigational information is edited and the aircraft's position is computed; Pass 3 (ATTALT processor) corrects for ocean waves, evaluates system performance, and locates the laser spot on the ocean bottom; Pass 4 (GRID processor) reconciles ambiguity among dense, noisy depth and position information and produces a minimum variance sparse grid of depth estimates.

Pass 1 processing techniques are based on research results concerning depth measurement bias caused by light propagation in sea water. The bias estimates result from a Monte Carlo simulation performed by Guenther and Thomas (1981).

Pass 2 utilizes computer/operator interactive CRT display techniques for editing purposes and computes position via an interactive process using Sodano inverse formulas. The code used for computing positions was acquaired from the NAVOCEANO Computer Branch (1972).

Pass 3 utilizes optimal filter techniques to resolve aircraft altitude, pitch, roll, and sea surface waves via a minimum variance solution on the slant range laser measurment from aircraft to sea surface. The dynamics of the laser scanning pattern and sample sequence permit the state vectors of the optimal filter model to operate with distinct separation in correlation times (Byrnes and Fagin, 1978).

Pass 4 also operates via optimal filter theory and is designed to treat both depth error and position error simultaneously. The minimum variance gridding process takes advantage of redundant observations and generates a product with reduced random error (Byrnes, 1979).

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